A Proposed Roadmap for Optimizing Predictive Maintenance of Industrial Equipment

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***Abstract*—Now-a-days, the maintenance management of industrial equipment, particularly in the aeronautical industry, has evolved into a substantial challenge and a critical concern for the sector. Aeronautical wiring companies are currently grappling with escalating difficulties in equipment maintenance. This paper proposes an intelligent system for the automated detection of machine failures. It assesses predictive maintenance approaches and underscores the significance of sensor selection to optimize outcomes. The integration of Machine Learning techniques with the Industrial Internet of Things (IIoT) and intelligent sensors is presented, showcasing the heightened accuracy and effectiveness of predictive maintenance, especially in the aeronautical industry. The research aims to leverage Predictive Maintenance for enhancing the performance of production machines, predicting their failures, recognizing faults, and determining maintenance dates through the analysis and processing of collected data. Employing sophisticated code, the study emphasizes real-time data collection, data traceability, and enhanced precision in predicting potential failures using Machine Learning. The findings underscore the collaboration between sensors and the synergy of Machine Learning with IIoT, ultimately aiming for sustained reliability and efficiency of predictive maintenance in aeronautical wiring companies.**

***Keywords*—Predictive maintenance; intelligent system; aeronautical wiring companies; machine learning; IIoT**

I. INTRODUCTION

Maintenance in aeronautical wiring companies is crucial to ensure the safety and reliability of aircraft electrical systems. Technicians conduct regular inspections, testing, and repairs to meet aviation standards. Adherence to regulations and the adoption of advanced techniques like predictive maintenance are essential for optimal performance and safety. In the previous article [1], a maintenance management model employing machine learning was implemented. This model utilizes an expert system to support diagnostics and generate action plans for repairs based on the type of failure. The expert system reduces maintenance intervention time, minimizes machine downtime, and serves as the foundation for predictive maintenance.

The main objective of this paper is to significantly improve the maintenance approach by integrating intelligent sensors. These sensors ensure seamless communication via the (IIoT) and are connected to a central server to collect real-time data, which is efficiently stored in a database. Machine learning leverages this data to predict potential breakdowns and detect patterns and trends in the state of industrial equipment. With this proactive approach, corrective measures can be swiftly taken to minimize unexpected downtime, reduce high maintenance costs, and ensure continuous reliability and efficiency in the aeronautical industry.

This paper proposes an intelligent system for automatically detecting failures in machines. The initial focus is on presenting and evaluating the maintenance predictive approaches, including the approach detailed in article [1]. Following that, an in-depth discussion ensues regarding various sensor types and their significance in optimizing and predicting outcomes. Emphasis is placed on selecting sensors that support inter-sensor communication, fostering collaboration, and leveraging IIoT to enhance predictive maintenance capabilities, particularly in the aeronautical industry.

Additionally, the integration of Machine Learning techniques with IIoT and intelligent sensors is showcased, illustrating their synergistic impact on improving the accuracy and effectiveness of predictive maintenance processes.

The main contribution of this paper is integrating intelligent diagnostic sensors with Industrial Internet of Things (IIoT) technology and machine learning analysis in aeronautical industries, specifically in wire cutting machines. This integration enables real-time data collection and storage in a centralized database. The ultimate goal is to optimize maintenance procedures, ensuring the long-term reliability and efficiency of cutting cable machines in aeronautical industries.

The structure of this paper is organized as follows: Section II provides a review of existing approaches. Section III presents materials and methods. In Section IV, the proposed model is introduced, and results and discussion are presented in Section V. Finally, the last section concludes by highlighting the main contributions and outlining future work.

II. REVIEW OF EXISTING APPROACHES

To establish a detailed context for exploration, a comprehensive analysis of predictive maintenance in the industrial sector is undertaken in the following sections. Furthermore, numerous research studies have investigated different facets of intelligent sensor integration for maintenance in smart factories [2].

Specifically, Song et al. [3] focus on smart sensors used to monitor rock bolts' condition and integrity to minimize economic and personnel losses. Jin [4] discusses multifunctional sensors suitable for industrial production, while Feng [5] delves into sensors for intelligent gas sensing. Paidi

[6] examines intelligent parking sensors that utilize machine learning to replace ultrasonic sensors. In addition, Talal and Sony [7] [8] characterize sensors for health monitoring. The concept of combining smart sensors and smart factories, a crucial aspect of Industry 4.0, is commonly found in literature reviews. Lee [9] illustrates the use of smart sensors to evaluate and diagnose individual devices in smart factories.

Expanding the review, Strozzi in [10] emphasizes the actual transition and implementation of large, intelligent factories. Pereira and Álvarez [11] [12] focus on implementing smart factory principles and highlight that effective value creation depends on the chosen method of implementation.

The implementation process, which involves managing technological and organizational changes and desirable competencies, is further addressed by Sousa [13] and Lee et al. [14]. They also draw attention to the gap between recent research and the actual level of deployment.

Regarding maintenance in intelligent factories, several literature reviews revolve around predictive maintenance. Carvalho [15] concentrates on machine learning methods, considering them a promising tool for predictive maintenance. Sakib [16] observes a shift from reactive service activities to proactive, predictive maintenance and relates it to the context of Industry 4.0.

In specific applications, Olesen and Shaker [17] study practical use in thermal power plants, while Fei [18] focuses on predictive maintenance in aircraft systems. As for the approach [1], a maintenance management model utilizing Machine Learning has been proposed to optimize and enhance reliability. The model includes a referential and expert system that aids in diagnosing breakdowns, assigning technicians, and generating detailed repair action plans. The expert system reduces intervention time, minimizing machine downtime, and facilitates predictive maintenance implementation.

So, studies focus on the use of smart sensors to monitor conditions, enhance safety, improve efficiency and implement predictive maintenance techniques, with the aim of minimizing economic and human losses. However, it should be noted that the integration of smart sensors via IIoT and real-time data collection for predictive maintenance in the aeronautical industry, particularly in cable-cutting machines, has not been discussed in these studies.

The current studies primarily concentrate on utilizing smart sensors to monitor conditions, enhance safety, improve efficiency, and implement predictive maintenance techniques, all with the objective of reducing economic and human losses. However, it's crucial to note that the aeronautical industry has not received comprehensive attention in these studies, specifically regarding the integration of smart sensors through the IIoT and real-time data collection for predictive maintenance, especially in the context of cable-cutting machines. This identified gap calls for special consideration to fully exploit the potential benefits of technology in this specific field of aviation. Further research and development in this area can lead to significant advancements and improvements in maintenance practices within the aeronautical industry. Although the proposed expert system successfully reduces technician assignment and maintenance intervention time [1], it faces a notable limitation. The data collected by technicians may be unreliable, which can have adverse consequences on the maintenance process. One major limitation of this approach is its failure to identify the specific nature of equipment failures. Human involvement is still necessary to diagnose the equipment and pinpoint the failed components. However, this manual approach to data collection slows down the maintenance process, resulting in machine immobilization.

The diagnostic aspect is crucial as it allows for accurate identification of the failure and the specific part that requires replacement. Without this information, machine downtime can be prolonged, especially if there is an inadequate stock of spare parts available. Therefore, improvements are needed to enhance data reliability and the system's ability to diagnose failures effectively.

So, the primary goal is to enhance the maintenance approach significantly by employing intelligent sensors specially created for diagnostics. These sensors will communicate through the IIoT, enabling the real-time collection and efficient storage of data in a centralized database. Subsequently, machine learning will analyze the data to predict potential breakdowns. By adopting this proactive strategy, intervention actions can be implemented before issues escalate, thereby minimizing downtime, maintenance expenses, and disturbances in the production process. The ultimate objective is to optimize maintenance, ensuring the reliability and efficiency of industrial equipment.

III. Materials and Methods

A. Introduction to Sensors

The new requirements imposed on industrial systems in their operation and in their production and in the quality of their production, require a very elaborate strategy in the control of these installations. The difficulty is to have relevant and reliable information that allows to generate an effective corrective action. Sensors are these sources of information.

The development of information processing capabilities allows the control and automation of increasingly complex systems.

The calculation possibilities of the controlling parties seem to be limited only by the quantity and quality of the data provided to them. So Sensors play an important role in the automation of any kind of application by measuring and processing the data collected to detect changes in physical things. Fig. 1 illustrates the sensor operation.

Intelligent sensors are multi-component measuring devices that are self-calibrating, self-optimized, and simple to integrate into the environment for high connectivity, according to Eifert [19]. Furthermore, intelligent sensors possess process intelligence and are capable of generating multidimensional data information.

A sensor is a device, module, machine, or subsystem that detects events or changes in its environment and relays the information to other electronics, most commonly a computer processor [20]. A sensor converts the physical parameters into a measurable digital signal, which can then be presented, read or processed.

Several classifications of sensors exist, established by different authors and experts. There are some that are very simple and others that are very complex. In this classification of sensors, they are divided into two categories: active and passive. Active sensors are those that require an external excitation signal or power signal. In contrast, passive sensors do not need an external power supply and are able to generate an output response directly.

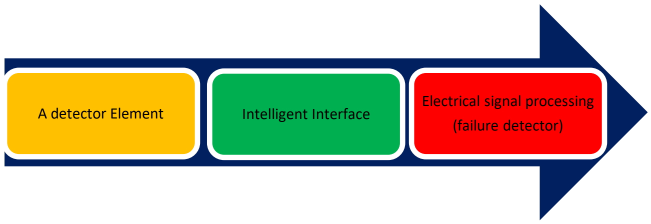

Fig. 1. Illustration view on the working of sensor.

B. *Different types of Sensors*

There are different types of sensors varying from the simplest to the most complex. Sensors are classified according to their specifications, their conversion method, the type of material used, the physical phenomenon of detection, the properties of what it measures and the application field [21].

- Proximity Sensors: Without making direct physical touch, proximity sensors make it simple to determine the location of any adjacent object. It detects the existence of an object by simply looking for any fluctuation in the return signal after emitting electromagnetic radiation, such as infrared. Numerous types of proximity sensors, including inductive, capacitive, ultrasonic, photoelectric, magnetic, and others, are available and are aimed at various purposes. This specific sort of sensor is frequently utilized in applications that demand efficiency and security. This sort of sensor has several applications, including object detection, item counting, rotation measurement, object positioning, material detection, movement direction measurement, parking sensors, and others. The best applications for proximity sensors are found in a variety of industries [21] [22] [23].

- Position Sensors: By sensing motion, the position sensor determines the presence of humans or objects in a specific region. It can be used in home security to track the doors and windows of rooms and appliances from any location. It informs them of the open or closed state at all times and can follow intruders while they are away. It can be used in health care monitoring to track the location of patients, nurses, and doctors in a hospital [24], as well as in agriculture to track the whereabouts of animals [25].

- Pressure Sensors: Liquid or other forms of pressure are used in a variety of devices. These sensors enable the creation of IoT systems that monitor pressure-driven systems and devices. Any variation from the typical pressure range alerts the system administrator to any issues that need to be addressed [26][27] The use of these sensors is beneficial not only in production but also in the maintenance of complete water and heating systems since it is simple to detect any pressure fluctuations or decreases [20] [28] [29].

- Temperature sensors: It primarily used to control air conditioning, freezers and other environmental control devices. Now they are used in manufacturing, agriculture and healthcare. Since a defined ambient and device temperature is required for most equipment in the manufacturing process, this type of measurement can still be used to improve the production process. Soil temperature, on the other hand, is crucial for crop growth in agriculture. It helps the plants to grow properly, which results in optimal results[20].

- Chemical Sensors: In the world, there are various types of chemical sensors, some of which are used to measure the chemical composition of the environment. By monitoring chemical plumes in the environment, a wireless chemical sensor network can monitor air quality [30].

- Occupancy sensors: The presence sensor, also known as the occupancy sensor, detects the presence of individuals or items in a specific area. The sensor can be used to detect numerous characteristics such as temperature, humidity, light, and air from a distance. The authors provide a similar use of these types of sensors in [31].

- With regard to the choice of intelligent sensors in the industrial field for predictive maintenance and specifically for aeronautical cable cutting machines as discussed in the previous article [1], specific criteria for collecting the data needed for early detection of failures need to be taken into account.

- The various intelligent sensors to be installed (temperature, vibration, pressure, etc.) must be able to communicate with each other to share the data collected. In addition, it is essential to check that the sensors are capable of collecting data at an appropriate frequency to enable real-time monitoring and rapid detection of anomalies. It is essential that these intelligent sensors support IIoT-compatible communication technologies, making it easier to collect and analyze data remotely, as well as integrating them into more comprehensive predictive maintenance systems.

It is also important to ensure that these sensors provide useful information that can be easily interpreted to analyze the state of the machine. The data collected must be relevant for predicting breakdowns and contributing effectively to the maintenance planning process.

Another crucial aspect is to ensure that the sensors can be easily integrated into the existing cable-cutting machine without disrupting its normal operation. Successful integration ensures that the sensors fulfil their role without compromising the overall performance of the machine.

C. About PLCs

PLCs are industrial automation devices that perform two main functions: measuring process parameters using sensors and controlling equipment according to specific programs [32].

These specialized systems solve sequential and combined logic problems using programmable configurations. PLCs are used in a wide range of applications due to their ease of programming, accessibility and high reliability. They are equipped with digital or analogue input and output cards. PLCs are programmed using various communication protocols and specialized software [32]. PLC is considered as the brain of the automation setup, controlling and coordinating various industrial processes. The PLC interprets the sensor data to trigger appropriate actions. The seamless integration of sensors with PLCs empowers industries to monitor and regulate processes with enhanced accuracy, efficiency, and safety.

IV. Proposed Work

- Using IIoT, a traceability system has been developed to ensure communication between the PLC and the server through the MQTT communication protocol. Through this integration, a high-performance traceability system has been implemented to ensure real-time data collection and monitoring via a dashboard.
- Firstly, connecting the sensors to the IIoT network allows continuous data collection on various monitored parameters such as temperature, pressure, vibrations, etc. This data is then transferred to a centralized server for storage and analysis.

Data traceability makes it possible to track the complete history of measurements made by the sensors. This provides a complete and detailed overview of how parameters evolve over time, making it easier to identify trends and anomalies.

Real-time data collection enables proactive monitoring of equipment. Sensor values are constantly updated, enabling unusual variations to be detected quickly. This real-time information can be used to make rapid decisions and avoid expensive failures. With an intuitive dashboard, users can view collected data, trends, alerts and predictive maintenance information. The dashboard can display graphs, customized dashboards and notifications when significant thresholds or deviations from normal values are exceeded.

V. Results and Discussion

By using Machine Learning techniques, the collected data can be analyzed to predict potential failures.

Machine Learning algorithms are trained to recognize patterns and warning signals that indicate imminent failure. These predictions enable maintenance activities to be planned proactively, avoiding production interruptions and reducing the costs associated with unexpected breakdowns.

A model will be created by integrating IIoT and artificial intelligence. this model uses sensor connectivity, data traceability, real-time data collection and predictive analysis to improve predictive maintenance. This optimizes operations, minimizes unplanned downtime and delivers significant savings in maintenance and repair costs.

As shown in Fig. 2, the proposed model for maintenance management demonstrates the key role that IIOT & AI play in failure prediction and production line optimization.

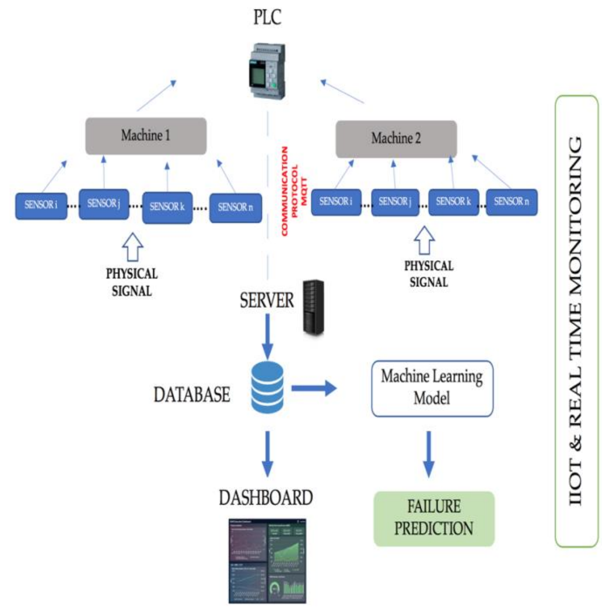

Fig. 2. Modeling of the maintenance process using intelligent sensors.

To implement the maintenance optimization approach, extensive and sophisticated code has been developed. This code plays a central role in the collection, processing and analysis of data from intelligent sensors interconnected via the IIoT (Industrial Internet of Things).

The first step in development was to create a communication interface that enables the sensors to transmit their measurements in real time to the designated data storage server. With this seamless connection, a huge amount of data can be collected from different pieces of industrial equipment, providing a global view of their operating status.

Once the data had been collected, the core of the code was based on the use of machine learning. A predictive model has been trained using advanced machine learning algorithms, capable of detecting patterns, trends, and anomalies in the sensor data. This model is continually refined and updated as new data is collected, allowing it to improve in terms of accuracy and reliability.

The pseudocode that schematically illustrates the main steps in this approach is shown in Figure 3. The pseudocode describes the general logic of the algorithm, including data pre-processing steps, model training, failure prediction techniques, and maintenance decision making.

Using this extensive code and machine learning approach enables the prediction of potential failures with enhanced precision. Anticipating problems before they occur allows proactive planning and execution of maintenance interventions, minimizing unplanned downtime and maximizing the availability and efficiency of industrial equipment.

```
M1.Listsensors=[S1...Sn]
M1.sensorAttributes=[temperature,pressure,...vibration] #n_feature
M2.Listsensors=[S1...Sm]
M2.sensorAttributes=[temperature,pressure,... vibration]  #m_feature


for sensor in M1.Listsensors:
    collect M1.sensorAttributes[sensor] from M1.Listsensors[sensor]


for sensor in M2.Listsensors:
    collect M2.sensorAttributes[sensor]  from M2.Listsensors[sensor]


DATA={"M1":M1.sensorAttribute ;"M2":M2.sensorAttribute}

Send DATA  to Server
#PLC -SERVER COMMUNICATION USING MQTT PROTOCOL
Stock DATA in DATABASE
Schematize and Monitore DATA by a realtime Dashboard
Analyse collected DATA BY ML MODEL
Make failures prediction
Display on Dashboard
```

Fig. 3. Proposed pseudocode.

In summary, the extended code and the methodology illustrated by the pseudocode in Fig. 3 provide a powerful decision-support tool, enabling the maximization of the reliability and performance of these industrial assets while reducing the costs associated with corrective maintenance.

VI. Conclusion and Future Scope

In conclusion, the adoption of smart sensors and the Industrial Internet of Things (IIoT) to enhance the maintenance approach represents a significant advancement in the industry. This proactive strategy, based on real-time data analysis through machine learning, provides the opportunity to anticipate potential failures and take action before they escalate into major issues. For aerospace companies, especially those utilizing cable cutting machines, this approach ensures not only optimal performance of their equipment but also precise traceability and real-time monitoring of each operation.

In future work, implementation of predictive maintenance using the proposed model is planned. This approach will further enhance the ability to foresee and prevent failures, thereby contributing to more efficient industrial operations management. By combining technological expertise with a proactive approach, the goal is to ensure continuous and reliable production while optimizing costs and maximizing the lifespan of equipment.

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